The

Kentucky Geological Survey

WILLARD ROUSE JILLSON

DIRECTOR AND STATE GEOLOGIST

SERIES SIX

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The Sixth Geological Survey

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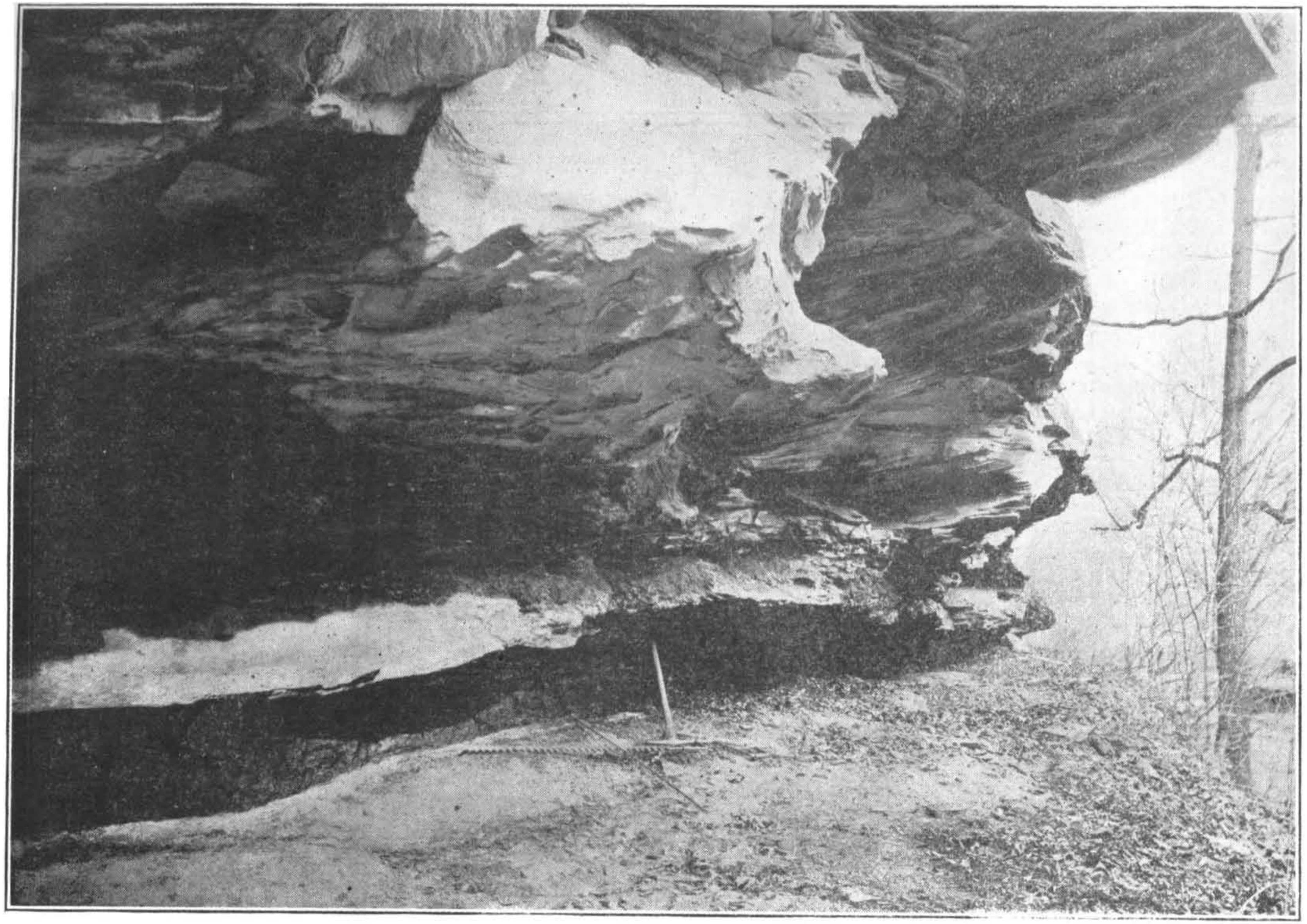

THE WHITESBURG COAL AND SANDSTONE "ROCKHOUSE" ROOF.

This characteristic view of the well known Whitesburg coal and its superimposed thirty feet of cliff forming sandstone may be seen on Otter Creek just above its juncture with the Middle **Fork of the Kentucky River** in Perry County.

THE
SIXTH GEOLOGICAL SURVEY

An Administrative Report of the Several Mineral Resource and General Geological Investigations Undertaken and Completed in Kentucky during the Biennial Period 1920-1921

By

WILLARD ROUSE JILLSON
DIRECTOR AND STATE GEOLOGIST

PRESENTED WITH TEN SEPARATE
MISCELLANEOUS GEOLOGICAL PAPERS

BY

GEORGE P. MERRILL,
STUART WELLER
WILLARD ROUSE JILLSON
STUART ST. CLAIR
AND
CHARLES STEVENS CROUSE

Illustrated with 101 Photographs
Maps and Diagrams

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THE KENTUCKY GEOLOGICAL SURVEY

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PREFACE

Applied geology is of great economic value to every State in which natural resources are only partly developed. This is especially true of Kentucky where the great body of mineral resources are now less than 20% under commercial operation. An ideal arrangement would be one where the State would have completed the base (topographic) mapping and the preliminary geological-resource surveys prior to the opening up of any oil, coal, natural gas, asphalt or other field. During the period of proving up such a field, State employed geologists could well work hand in hand with the operators, and assist them greatly in their efforts to win the resources desired.

Unfortunately this ideal arrangement has never existed in Kentucky, though it has to some extent in other States. With only 46% of Kentucky base (topographic) mapped, and with an area approximating that of sixty counties not covered by any accurate maps at all, the function of the Kentucky Geological Survey has always been crippled and held in restraint. The day of a 100% efficiency of the Kentucky Geological Survey seems yet to be in the distant future.

During the last biennium a large number of subjects of great economic value to this State have been investigated, however, by the Kentucky Geological Survey. A full account of these investigations is presented herewith in the first paper of this volume entitled, "The Sixth Geological Survey." A number of these economic papers are included within the covers of this book, and should assist materially in an understanding of the geology and resources of the several regions covered. This report is issued in an original edition of one thousand copies.

W. R. Jillson

Director and State Geologist.

Old Capitol,
Frankfort, Kentucky.
December 15, 1921.

CONTENTS

ILLUSTRATIONS

The Sixth
Geological Survey

VI

RETORTING METHODS AS APPLIED TO KENTUCKY OIL SHALES

By Charles Stevens Crouse,
Oil Shale Technologist.

The State of Kentucky has within its borders a hitherto untouched natural resource which in its potentialities is, perhaps, second to none. This potential source of wealth is compassed in the vast deposits of oil shale so abundantly found in various portions of the Commonwealth.

There are three separate and distinct groups of bituminous shales in Kentucky from any or all of which oil may be obtained but, owing to physical character and occurrence, only the lowest group, the Devonian or Black Shale, is considered commercially important at the present time. The next shale above the Devonian is the Sunbury which occurs toward the base of the Waverly (Mississippian) and is very similar to the Devonian and, in this paper, will be considered with it so far as retorting methods and commercial exploitation is concerned. The uppermost group of shales are found in the Pottsville (Pennsylvanian) at various horizons in the Eastern and Western Kentucky Coal Fields and their action when retorted is so different from that of either of the other shales that, for the purposes of this paper, they will not be considered.

Sufficient geologic and other field work has been done to show that there are approximately one thousand square miles of exposed shale available in Kentucky at the present time for immediate investigation and possible commercial operation. The above named acreage is the shale which it will be possible to mine by steam shovel methods and does not take into con-

sideration at all the practically inexhaustible deposits which lie below ground necessitating underground methods of mining for their recovery. Assuming an average shale thickness for this area of fifty feet, which assumption is conservative, and a weight per cubic foot of one hundred and thirty pounds, which is the average of twenty samples from widely separated points in the state, we arrive at the stupendous figure of 90,604,800,000 tons of shale immediately available for exploitation on a commercial scale.

Although no exhaustive sampling of these shales has been done to date, still that which has been done indicates that a recovery of about a half a barrel of crude oil to the ton may be generally expected throughout the shale area. In some places the recovery will be greater and in some less, but the figure quoted should be near an average for the entire deposit. Such being the case, the tonnage given translated into terms of crude oil shows that the shale area is actually an immense reservoir of oil containing something like 45,000,000,000 barrels of crude oil. This immense quantity of oil simply awaits the day when man, through his ingenuity, shall find the key to this vast natural storehouse, and liberate in a commercial way the oil locked up during the geologic ages past. That time, if it has not now come, is rapidly approaching. The purpose of this paper is therefore to describe the various keys that have been so far devised, and to see if one or more of them may not be used successfully.

The retorting problem, then, or, in other words, the production of oil and various by-products from the shale, is the big problem confronting all those who are planning on the working of shale deposits. Moreover, it must be borne in mind that not only is it a question of oil recovery, but also a question of the utilization of all the by-products possible. These by-products include ammonium sulphate, potash, coal tar products, spent shale, and other things not yet dreamed of, that will make the industry so diversified that it will not depend on any one thing for its profits, but on an increasingly larger number of products. In this way alone is there to be

found commercial safety for times of commercial prosperity and depression.

The greater part of the constructive work done in this state in the retorting of Kentucky oil shales has been accomplished by the writer in the Mining Laboratory of the University of Kentucky at Lexington. A great deal of work has been done, however, elsewhere, both by the United States Bureau of Mines and by private individuals with the shales of Colorado, Utah, California, etc., the so called Western Shales. The oil shale industry has been on a commercial basis in Scotland for some seventy odd years. The Western (American) Shales in some vital particulars are, however, quite different from the Kentucky Shales and, although it is stated on good authority that the Kentucky Shales are similar to those of Scotland and that the Scotch method of retorting might, therefore, be used in Kentucky, it still cannot be considered the best method as it now stands. We must for this reason look either to some modification of Scotch practice or to some altogether new procedure to give us the method that we wish.

There is no oil, or very little, in shale as such. That is oil cannot be extracted from shale by means of solvents or pressure. Rather is it in the form of what has been called "kerogen." This "kerogen" consists of particles of organic matter either of animal or vegetable origin or both and, before oil can be obtained, the shale must be heated in order to volatilize or gassify these organic compounds, thus forming various hydro-carbons. Subsequently that portion of the gas which can be condensed, is reduced to a liquid or crude oil. It will thus be seen that, in the first place, the quantity and quality of the oil obtained depends directly on the amount and character of the organic compounds in the shale. However the proposition is not qnite so simple as may appear because the gases, after they are formed, are very easily broken up or "cracked" by variation in heat so that, given a certain shale, both the question of quantity and quality of oil obtained is almost entirely a matter of heat control. It follows as a corollary that the amount and sort of oil produced may be varied

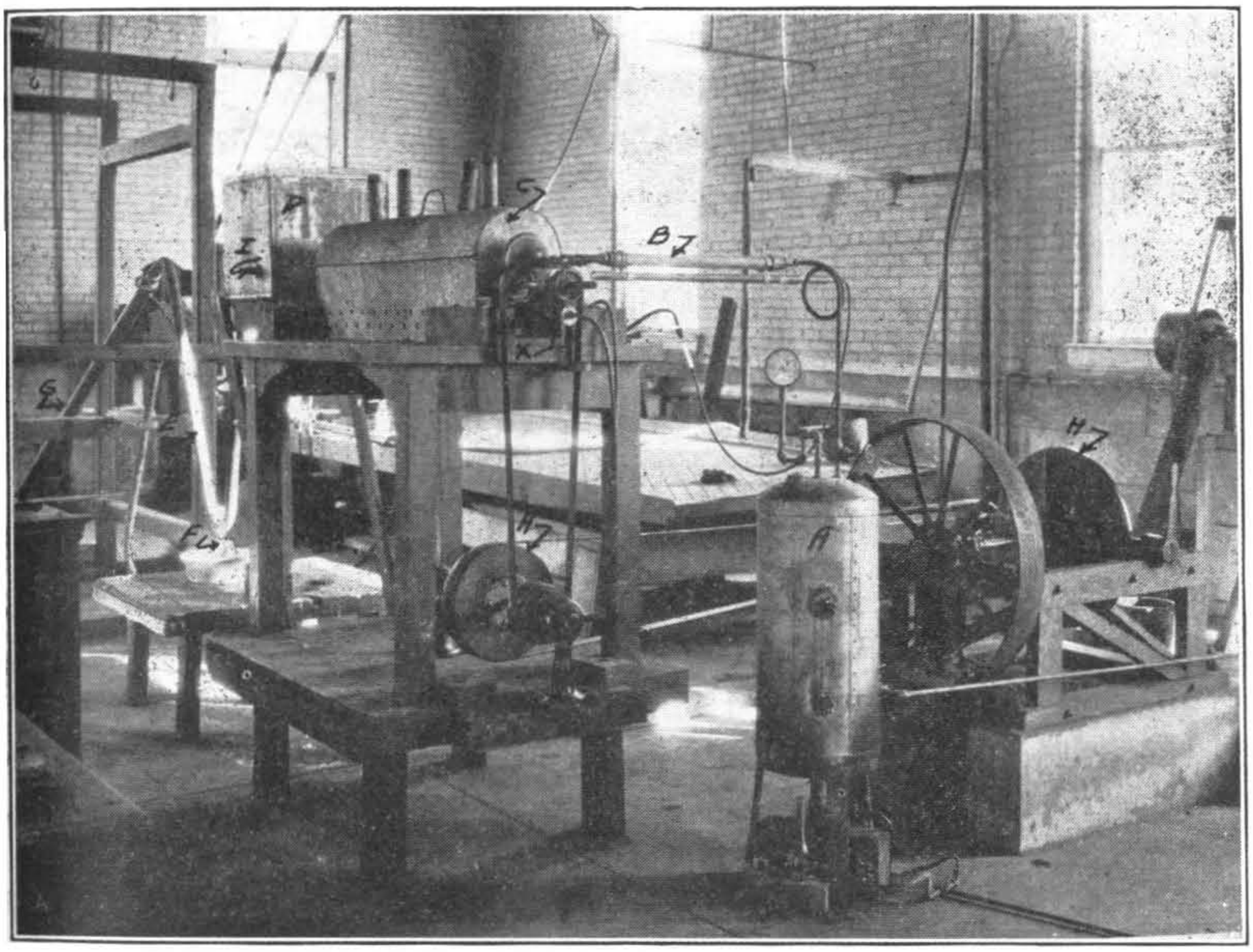
at will, within certain well defined limits, by the intensity of the heat applied and by its manner of application. The cardinal principle, then, of any method of retorting must be absolute heat control.

As before mentioned, all of the "kerogen" will not produce oil gas but some gas will be formed which is not condensable but which, nevertheless, is very valuable as it may be utilized, either by burning directly or in gas engines, as a fuel to operate a plant. In general it may be said that the ideal retort so far as the production of oil is concerned will be the one in which a maximum of oil is made with a minimum of fuel gas though all the fuel gas made must be conserved.

There is, in addition to the "kerogen" present, a varying amount of nitrogen in the Kentucky Shales a large part of which may be recovered as ammonium sulphate under the proper conditions of retorting. But a maximum recovery of ammonium sulphate requires somewhat different conditions than if oil alone be considered. Steam must be used and a high enough temperature developed to dissociate this steam so that it may react with the nitrogen to form ammonia which, in turn, by being passed through sulfuric acid, will form ammonium sulphate. But, as previously indicated, a higher temperature than that necessary to evolve the oil gas is undesirable because of the danger of "cracking" the oil gas into fuel gas and thus curtailing the production of oil. In the ideal retort, therefor, all the oil gas must have been evolved and withdrawn before the temperature is raised to such a point that maximum ammonia recovery is obtained. Also, for the latter result, steam must be used.

It has been stated that dissociated steam reacts with the nitrogen in the shale to form ammonia, but it does more than that. It also reacts with the fixed carbon in the shale, that is the carbon that is not volatilized by simple heating, to form water gas thus increasing the amount of fuel available for plant operation and this point is one that should be borne in mind because if enough gas can be made in retorting to supply all or most of the fuel needed one of the greatest items

of running cost is practically eliminated and the plant is almost self contained.



A LABORATORY UNIT RETORT.

This view, also taken from the driving or steam inlet end, shows the retort with the cover on and all connections made ready to operate. The boiler, superheater and driving mechanism are shown in the foreground while the dust catcher and part of the condenser system shows in the left background.

In addition to the products named a number of the reliable commercial laboratories state that water soluble potash to the amount of from four to thirty-eight pounds per ton of shale may be recovered from the spent material that has passed through the retort. While the retort used has nothing to do directly with the amount of potash recovered nevertheless it has an indirect bearing in that the more finely divided the shale the easier for the water to dissolve out the potash. In other words maximum potash recovery means fine grinding. On the other hand fine grinding costs are high so that an economic equilibrium will have to be found which, I think, may be when the shale is crushed to about pea size. From what has been said it will be seen, then, that the ideal machine will

be one that will treat shale crushed to about pea size or a little larger not only for the easy liberation of the potash content but also for the more efficient and rapid evolution of oil and fuel gas with consequent diminished danger of "cracking" and the better interaction of dissociated steam with the nitrogen and fixed carbon of the shale with the consequent decreased time of treatment and increased amount of both ammonium sulphate and water gas.

At the present time not enough research work has been done to determine what, if anything, may be done with the retorted or spent shale. Some of the suggested uses which are worthy of further investigation are as a raw material for vitrified brick, which seems reasonable as the spent shale consists of about fifty per cent silica, as a base for Portland cement, the necessary ingredients which may be lacking being added, as a road material when mixed with the tar or other material from the refining of the oil, etc. In all these suggested uses a fine degree of division is necessary giving additional proof that the ideal retort should be designed for treating fine, not coarse, material.

Bearing in mind the above it becomes evident that the ideal retort for the treatment of Kentucky oil shales must be one in which (1) absolute heat control is available, (2) the oil must be educed and withdrawn first and the bulk of the ammonia and water gas later, (3) provision must be made for treating shale of at least pea size, (4) there is practically no leakage of gas from the retort or of air into the retort and, preferably, a slight vacuum in the retort rather than a pressure. These are the technical points, but, in addition, there are the equally important commercial ones of (1) low first cost, which means easily obtainable and cheap materials of construction, (2) low operating costs, which includes a minimum of skilled labor required, (3) low upkeep and repairs, which means simplicity of design, (4) maximum thruput per unit compatible with efficient recovery of products, (5) continuous operation, which means no complicated parts and all parts liable to breakage easily reached for repairs.

With the above qualifications for the ideal retort in mind, an effort will be made to analyze some of the more prominent makes of retorts on the market today for their availability for use on Kentucky shales and to see how closely they conform to the ideal conditions outlined. The data on which these analyses are based is taken largely from that furnished by the owners of the various machines described and discussed. An attempt has been made by the writer to verify all statements submitted, but it is not impossible that some errors or misstatements may have slipped in.

All the retorts designed for the dry destructive distillation of oil shale fall naturally into two grand divisions, (1) vertical retorts which include the Scotch and modifications of the Scotch and (2) horizontal retorts in which the retort itself is stationary and the shale is conveyed through it by mechanical means or in which the retort itself revolves. The above classification covers all the known methods of educing oil from shale, except one. This latter one is a digestive process in which the pulverized shale is treated in hot oil instead of by a dry heat. A description of this essentially different method will be taken up later in the proper place.

THE SCOTCH PROCESS.

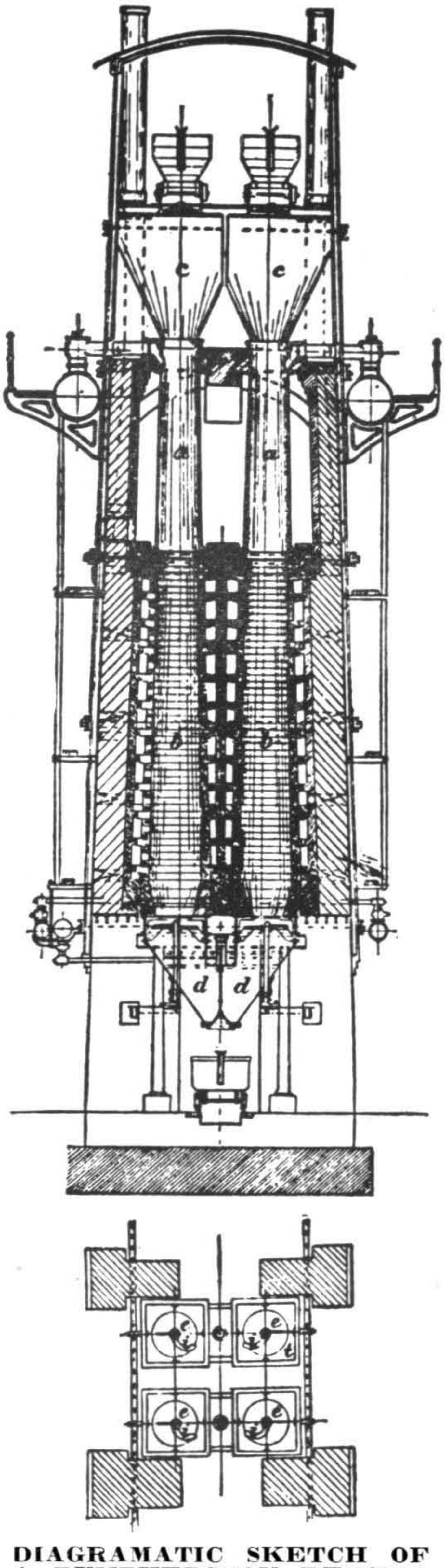
The shale industry in Scotland has been established since 1850 and the retort first used has necessarily undergone many changes since that time. Nevertheless the Pumpherston retort of today, which will be taken as an example of Scotch practice, is quite similar to the Young and Beilby retort which was patented in 1881.

The Pumpherston retort first came into extensive use in 1896 and twenty years later there were some fifteen hundred retorts of this type in operation in Scotland.

As shown in the figure, the shale, first crushed to a size not greater than six inches square, goes to the charging hopper "e" from which it passes into the upper, cast iron portion of the retort "a" in which the actual distillation takes place. This portion of the retort is 15 feet long, 2 feet in diameter at the top and 2 feet 4 inches at the bottom and is heated

externally, to a dull red heat, the oil vapors passing out below the hoppers through an iron main 2 feet 6 inches in diameter. The shale then slowly works its way into the lower portion of the retort "b," which is made of fire brick. This portion is 20 feet in length, 2 feet 4 inches in diameter at the top where it joins the cast iron portion and 3 feet in diameter at the bottom. Here the shale is subjected to a temperature sufficiently high to burn off all the carbon from the oil spent shale and, this being done at a high temperature in the presence of steam, ammonia is produced by the hydrogen of the steam uniting with the nitrogen of the shale, about sixty per cent of the total nitrogen being converted into ammonia and recovered. At the bottom of the fire brick portion there is a disk shaped table "e" which supports the column of shale in the retort this table being provided with a revolving arm "i" which removes the spent shale and maintains a movement in the shale column by revolving at regular intervals. This arm discharges the shale into the lower hopper "d" extending underneath several retorts and converging in such a manner that a single line of rails running below the center will allow the exhausted shale to discharge into cars from whence it is removed to the dump. Both portions of the retort are heated externally by the gas made in the process, when in sufficient amount, steam being introduced a short distance above the disk "e." In this type of retort a thruput of from four to five tons per day may be worked.

The Scotch Shales are mined underground, the method used being very similar to that used in mining coal in this country. The roof is supported by pillars and usually about twenty-five per cent of the shale is left under ground in mined out workings. The shale is carried to the surface, broken into pieces not more than six inches square, and then goes to the retorts. The gases are withdrawn from the retort as indicated in the the description of the retort, the oil gases condensed and the fuel gases scrubbed to recover ammonia and gasolines carried over and then used to heat the retorts. The spent shale goes to the dump. The crude oil obtained is then refined by meth-



DIAGRAMATIC SKETCH OF A PUMPHERSTON RETORT.
This retort and others similar to it are much used in Scotland for the extraction of oil and by products from shale.

ods similar to those used in refining natural petroleum though differing somewhat in some respects.

The shale now being retorted yields an average of almost 24.5 gallons of crude oil and about 35.7 pounds of ammonium sulphate per short ton with an average yield of about 9,800 cubic feet of fuel gas of a heating value of about 240 B. t. u. per cubic foot. According to Doctor Alderson of the Colorado School of Mines the profit on each ton of shale mined is approximately two shillings or, under normal rates of exchange, fifty cents. At the present time the entire shale industry of Scotland is controlled by Scottish Oils, Ltd., which is, in turn, controlled by the British Government.

The Scotch process as practiced today represents the evolution taking place in some sixty or seventy years and is undoubtedly very well suited to the conditions under which it is required to operate. The Scotch plants are in the midst of an industrial area where labor is plentiful and cheap, they have no domestically produced petroleum to compete with and there is a large demand for the ammonium sulphate produced. Under these conditions the small thruput of from four to five tons per day and the more or less wasteful methods of heat utilization are possible whereas in this country, under different conditions, it is doubtful if it would do at all.

The chief objection to the Scotch method of retorting oil shales, then is its small thruput per day which, with the necessarily large capacity demanded by steam shovel methods of mining, which will be used in Kentucky, would necessitate a large initial outlay for plant and a huge plant site.

The Scotch retort has been proved to be practical in Scotland and would undoubtedly work here, fulfilling as it does most of the requirements of the ideal retort but it is certainly not the most efficient that can be devised for Kentucky practice and, therefore, should not be considered too seriously.

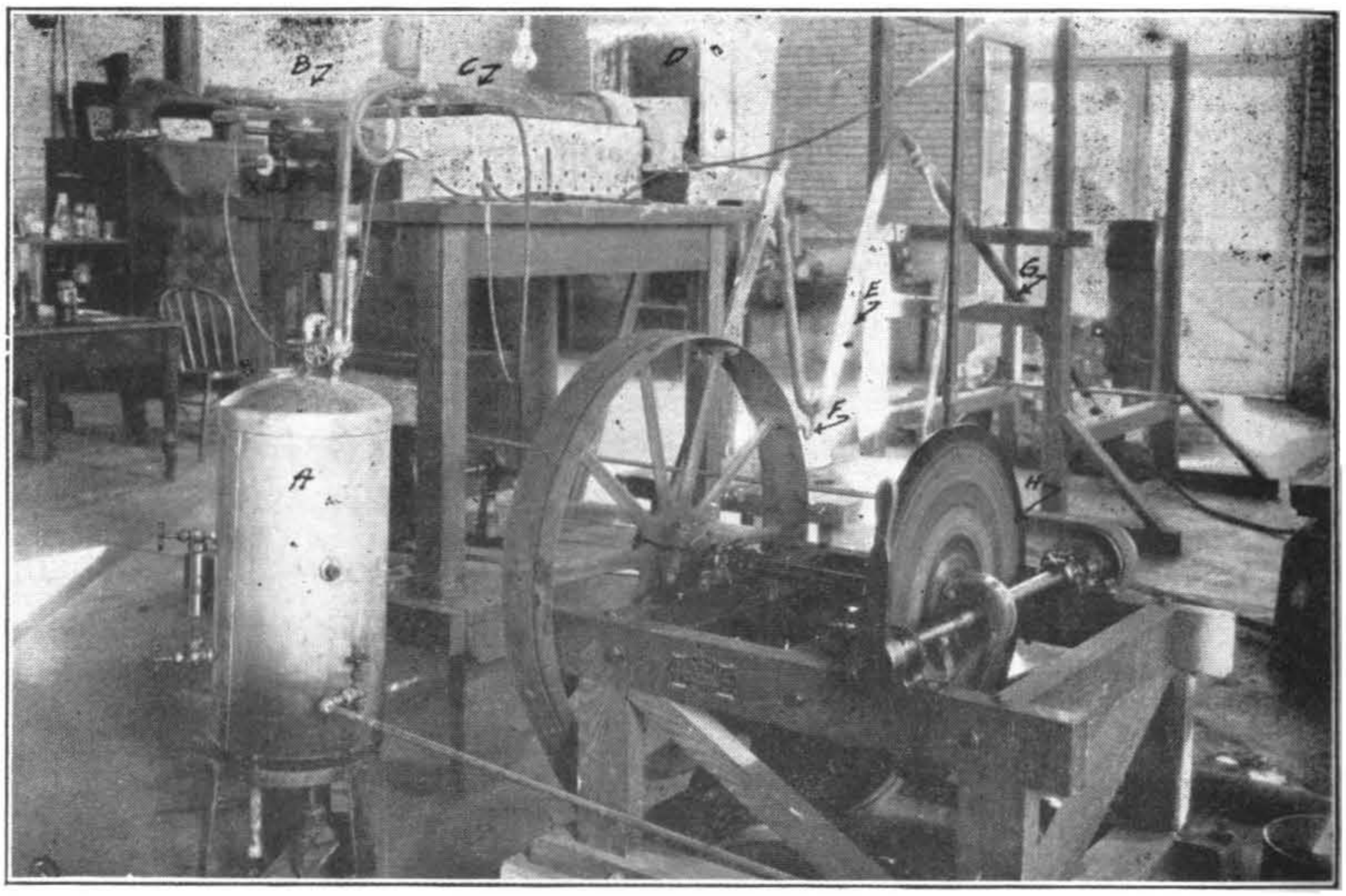
THE PROCESS DEVELOPED AT THE UNIVERSITY OF KENTUCKY.

This process has been developed by the writer and Mr. E. E. Hedges of New York, during about two years of research

work and the laboratory model in use at present is shown in the accompanying cuts.

It consists, essentially, of a hollow, revolving cylinder 30 inches long by 6 inches in diameter driven by a friction drive, at about fourteen revolutions per minute though this speed may be varied, a boiler for generating steam, a box with an interior baffle, into which the gas from the retort is first passed and the purpose of which is to catch any dust that may be carried out of the retort in the gas current, and a condensing system to condense the oil gas.

Cut number one gives a general view of the apparatus. In this cut "A" is the steam boiler heated by burners beneath it and in which about twelve pounds of steam is maintained during the duration of a run. "B" is a length of 2-inch pipe used as a superheater for the steam and heated by a burner beneath it as shown. "C" is the revolving cylinder or retort proper shown with the cover off. This cover is put on when the machine is operating in order to cut down radiation losses. "D" is the dust box or dust catcher into which the gases from the retort are first discharged and in which is a baffle placed at about sixty degrees from the horizontal. This baffle forces the gas current to make an entire change of direction so that the dust particles may drop out due to the action of gravity. The size of the box which is a 16-inch cube with a pointed bottom is also such as to retard the velocity of the gas current and in this way also assist in forcing the dust particles out of the gas stream. "E" is a V-shaped air condenser with trap "F" at the bottom of the V where the easily condensable gases are recovered and "G" is a straight, water cooled condenser where the more difficultly condensable gases are obtained. "H" is the driving mechanism with friction drive the latter giving an opportunity to vary the speed of the cylinder at will. "X" is a burner for supplying the necessary heat beneath the revolving cylinder, and it extends the entire length of the cylinder. The fuel used is natural gas, though the fuel gas made in the process could and would



SIDE VIEW LABORATORY MODEL.

This view, taken from the driving end, shows the retort in position but with the cover off. A good view is given of the driving mechanism, the steam boiler and superheater with the dust catcher and condensers showing in the background.

be used in a plant in the field. Fuel gas could be used in the laboratory were the proper apparatus available.

Cut three is a view from the condensing end of the appara- cylinder in place. The letters stand for the same parts as previously outlined. In addition "I" is a ¾-in. pipe let into the dust-catcher in which a thermo-couple is placed and the vapor temperatures thus noted.

Cut two is another general view with the cover over the tus showing the condensing system more in detail, the letters indicating the same parts as in the preceding print. There is an opening, not shown, in the discharge end of the retort, that is the end next the dust catcher, where the gases are discharged, for charging and discharging the shale. During the operation this opening is kept carefully closed by having the support trunion on that end screwed in.

METHOD OF OPERATION.

Bearing the above description in mind, a brief outline of the mode of operating should be readily understood. Ten

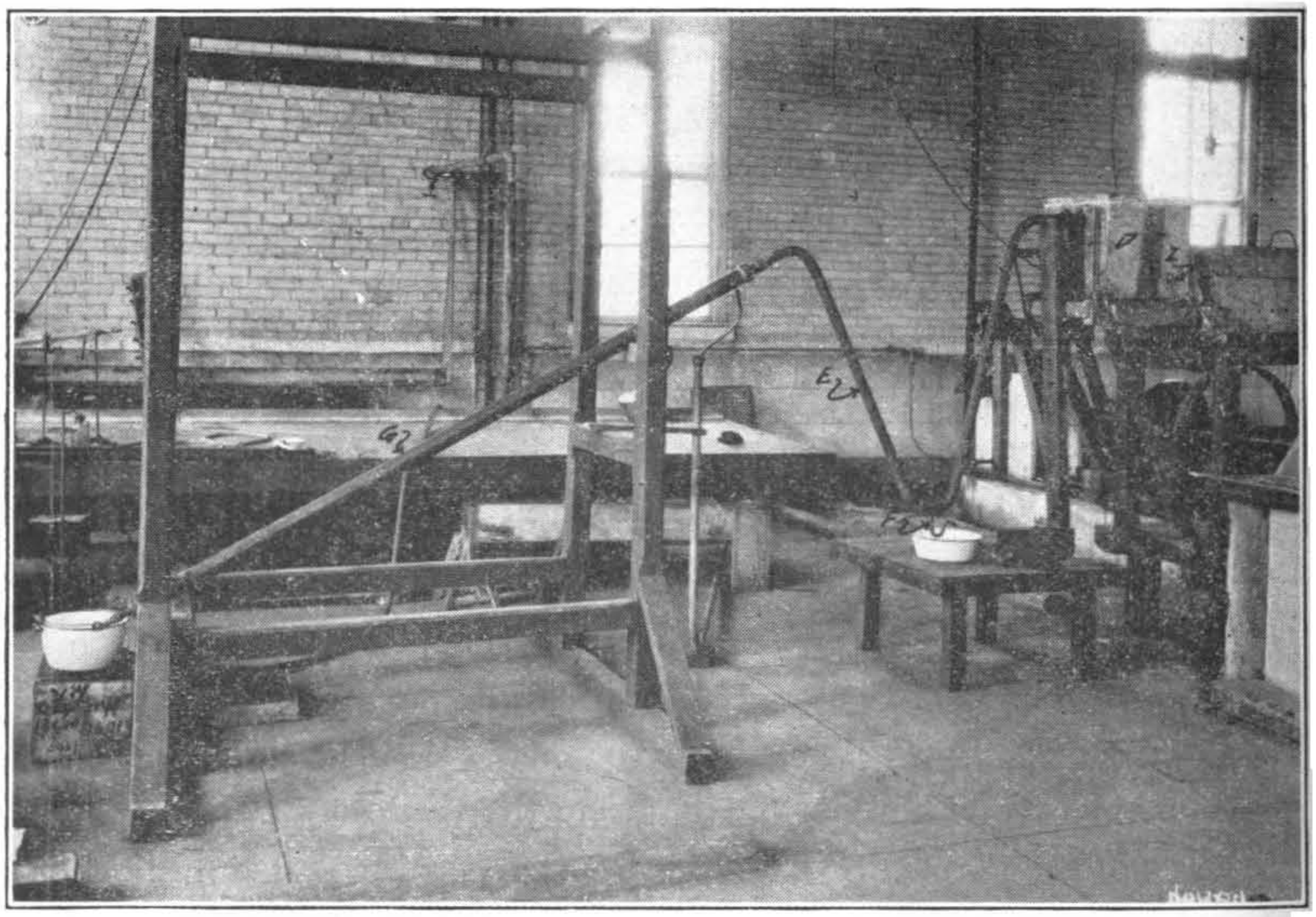
pounds of shale crushed to about quarter inch size and smaller particles are placed in the retort, the opening closed, and the retort put into position. A low fire is then turned on and the driving mechanism, a motor, is started. All joints are connected up and tight at this time, with the exception of the stuffing box which connects the stationary steam super-heating pipe and the revolving cylinder. The steam supply to the superheater is off and the boiler shows about ten pounds of steam. The heating is continued slowly till gas, evolved from the shale, shows at the stuffing box when steam is turned through the superheater to expel any water and insure the steam being dry before entering the retort and then the connection is made. A small amount of steam, just sufficient to sweep the gases out of the retort into the dust catcher and condensing system is then turned on. From this time on till the end of the run steam is continually passing through the retort, not only to act as a scavenger but also for its chemical action on the gases and the shale.

The heat is now gradually increased, temperature readings on the vapor being taken at frequent intervals, till no more oil appears either at the trap in the air condenser or at the end of the water condenser and very little gas is being shown at the latter point, the above conditions indicating that all the oil has been educed from the shale. The cooling water is now cut out of the water condenser and a full head of steam allowed to pass through the entire system in order to remove any oil that may adhere to the condensing pipes. The steam and the heat are then cut off, the rotation stopped and the retort is ready to be discharged.

The dust and whatever heavy oils that may have condensed in the dust catcher are then removed through the bottom of the box through an opening provided for that purpose and, after dewatering, are subsequently treated in a small stationary retort in order to recover their oil content. The oil which has been collected at the trap in the air condenser and at the end of the water condenser is now freed from water, mixed with the oil recovered from the dust box and carefully

measured, computations being made to give the results in gallons of crude oil per ton of shale.

Although the machine appears to be, and is, very simple, nevertheless it represents the evolution of the basic idea during a period of about two years of experimentation. The results obtained, to date, have been very satisfactory. The above described machine is the trial model of a commercial machine of which great things are expected.



GAS DISCHARGE AND CONDENSER.

This view shows part of the retort, at the extreme right, and in the center and left the condensing system. Since this picture was taken the pan, to hold the condensed oil, shown at the extreme left, has been replaced by a series of bottles connected to a suction thereby allowing scrubbing of the permanent gases.

This commercial machine will be 35 feet long by 4 feet in diameter and will have a capacity of about 25 tons of shale per day. It will consist of a revolving cylinder set at a slight angle to the horizontal the pitch being just sufficient to force the shale to move through the retort at the correct speed. The shale, crushed to about pea size, will be fed continuously at one end and discharged continuously at the other. A graduated heat will be maintained in the cylinder being just suffi-

cient to keep the gases from condensing in the feed end and increasing uniformly through the length of the retort to about 900 degrees F. at the discharge end. In this way the oil gases will be evolved from the shale as it travels through the retort, those which are formed first coming off at a low temperature and so on, and, as the gases are swept out and withdrawn through the feed end practically as soon as formed they will never be subjected to a higher temperature than that at which they are formed and, therefore, will run no danger of being cracked and changed into fuel gases.

At the lower or discharge end of the retort superheated steam will be admitted which will serve not only as a medium for sweeping the gases from the retort but will also be beneficial to both the quantity and quality of the oil made.

The oil spent shale, after it has been automatically discharged from the retort will pass into a water gas producer where the temperature can be raised sufficiently high so that steam, introduced in the usual way into the producer, will be broken up so that it will react chemically on both the nitrogen and the fixed carbon of the shale in the former case to give an increased yield of ammonia and, therefore, of ammonium sulphate and in the latter case to make water gas and thus increase the yield of gaseous fuel.

The spent shale as it is automatically discharged from the producer may be water treated to recover water soluble potash and then taken by conveyor belts or otherwise to the dump. The oil gas will be condensed and refined and the fuel gas scrubbed to recover light oils, ammonia, etc., and led to gasometers from whence it can be withdrawn, as needed, for fuel purposes.

A great deal cannot be said about the results to be expected commercially from this retort as no commercial unit has yet been built although one is in process of construction at the present time but the machine as outlined comes as near as any known to meeting the conditions of the ideal retort and the results from the laboratory model in both quantity and quality of oil and by-products obtained have been such as to indicate

that this machine will work as well if not better, on Kentucky shales, than any of the other processes described. No claim is made that this is the only machine that will take the oil from shale, but the results obtained taken in conjunction with its simplicity, low first and running costs, and large thruput per day would seem to show that it is one of the few, at least, that may be successfully utilized commercially on Kentucky shales.

THE RYAN PROCESS.

As previously stated, the Ryan Process is not one of destructive distillation, but is claimed to occupy "the middle ground between the range of a simple solution of contained oils and substances in some solvent under moderate temperatures and that of destructive distillation. It generates no gas———."

The Ryan Process consists of pulverizing the shale till about fifty per cent will pass a one hundred mesh screen. It is then fed, by means of a screw conveyor, into air tight kettles of hot oil, which has been stripped of its lighter fractions. The shale is fed near the bottom of the kettle and beneath the surface of the oil at a temperature above 680 degrees F., the approximate working temperature of the process.

The whole mass is then agitated by means of revolving arms. The hydrocarbons of the shale is split up and a distillate comes off with the characteristic odor of shale oil without producing any appreciable amount of gas. This distillate, which consists largely of the lighter oils formed, begins to come off immediately after the introduction of the shale and is condensed and recovered. After this part of the process is complete the digestive oil and the shale residue are removed from the kettle and separated mechanically by means of a centrifugal motion. They are twice washed with light oils during the operation. The nearly dry shale is then treated destructively in another kettle to recover wash oils and the remaining portions of shale oil which were not liberated by simple digestion. In this second stage, which is simply destructive distillation, some noncondensable or fuel gas is formed. It will be further noted that there is no recovery of ammonia.

The estimated costs of treating a ton of the Western Shale on the basis of a thousand ton a day plant are given as 75c for mining and delivery to digestor plant, crushing and grinding 15c, operation of digestor plant 25c, overhead, interest, depreciation, etc., 35c, making a total of $1.50 per ton treated, which compares very favorably with estimated costs of other processes. This estimate may be conservatively regarded as too low rather than too high.

To recapitulate, the Ryan Process consists of four separate and distinct steps each one requiring its own separate and distinct machinery, i. e. pulverizing, treating in the digestor, separating partially spent shale and digestion oil, treating this partially spent shale destructively. The claims for the process are: (1) a much larger oil recovery than by destructive distillation, (2) twice as much oil or more, (3) a better quality of oil so far as degree of unsaturation is concerned, and (4) all this at no more and possibly a lesser cost than that of other processes. Against these claimed advantages are the evident disadvantages of, (1) complication of plant with all the consequent chances of break downs and necessary care and skill in operation, (2) magnitude of plant for a given tonnage comprising as it does not only a digestive but also a destructive plant, (3) very little fuel gas made necessitating the inconvenience and cost of an extraneous fuel supply, (4) no ammonium sulphate made which puts the burden of profits on the oil alone or, at best, on the oil and spent shale. Taking everything into consideration, then, a comparison of the Ryan Process and any destructive distillation process is one of economic balance. Will a greater recovery of oil with a less degree of unsaturation be worth more than the loss of gas and ammonia and the greater magnitude and complication of the commercial plant?

For some six months a laboratory plant of this process has been in operation on Kentucky shales in the Mining Laboratory at the University of Kentucky and the writer has had an excellent opportunity for careful study of it. At the same time the machine developed at the University has been in operation

at the same place on the same shales. While the Ryan Process in some cases has shown a greater recovery of oil of a greater degree of saturation still the difference between the results from the two processes have not been very marked, never approaching two to one, and there is no question but that destructive distillation as exemplified in this retort, at least, is much simpler as well as showing fuel gas and ammonia recovery.

There is no question but that the Ryan Process will produce oil and a lot of it, probably more than most if not all processes of destructive distillation, but it fails to meet two of the important requirements of the ideal process, viz. simplicity which includes the time element or thruput per day per unit and diversity of products and, in addition, its claimed superiority of producing oil with a greater degree of saturation than that produced destructively is not, according to some refinery engineers, nearly as important as it may seem.

The successful commercial application of the Ryan Process to any particular problem, then, will depend entirely on whether the increased oil yield will counterbalance the undesirable features enumerated. It would seem as though there is much room for doubt whether this process will be any better, or as good as the best methods of destructive distillation from a profit-making standpoint which, after all, is the criterion by which all processes must be judged.

THE SIMPSON PROCESS.

This system of working oil shales is the result of some six years' work on the subject by Mr. Louis Simpson of Ottawa, Canada, and falls under the classification of vertical retorts. In this process the oil shale, after mining, is sent to the crusher house which contains a coarse crusher, a fine crusher, two screens to remove the fines and to return the oversize to the crusher, and a magnetic roller to remove "tramp iron." The shale, crushed to pass a half inch but be retained on a quarter inch screen, is then conveyed into and through dryers heated by the waste gases from the steam boilers after the main part of their heat has been removed in order to preheat the gases

for educing the oil from the shale as will be explained later. These dryers are for the purpose of furnishing shale to the retorts of the same physical characteristics at all times of the year. From the dryers the shale goes again to screens to remove the last of the fines and from these to bins over the retorts.

From the bins the finely crushed shale passes into each of the two chambers of a double retort being fed by a special feeder which feeds continuously in a small dribble. These chambers are vertical and rather narrow in width and so designed that the top of the shale in each chamber assumes the shape of a pile with two long sides or slopes thereby presenting the greatest possible surface to the action of the preheated gases with which the space unoccupied by the shale is kept filled. These two chambers join at the bottom of the retort and the shale is removed continuously at this point by means of two discharge rollers.

The heat required to produce the oil gas from the shale is furnished by admitting preheated gases into the retort in direct contact with the shale, there being no outside application of heat. These gases are the product of a previous operation and are admitted at several points two of which are located at the feed end of the chamber. The volume of these gases can, of course, be regulated as desired. It is claimed that not only do these preheated gases heat the shale to the necessary temperature for educing the oil but also act as a carrier for the oil vapors formed by their action and in addition act as a diluent thus lowering considerably the vapor pressures and temperatures required for the action.

The gases and oil vapors are removed from the retort at several points through holes specially designed so that they will not become clogged. The light-oil-vapor-gas mixture comes off first and the vapors are condensed by being passed through the water cooled condensers the heavy-oil vapors being removed and condensed separately. The water used in condensing the light-oil-vapors is used again in the heavy oil

condensers from whence it is delivered at a temperature sufficiently high to permit its being fed directly into the boilers.

The retort chambers are made of steel plates and a bench of retorts, consisting of four double retorts, is enclosed on all four sides by an inner steel wall welded to make it gas tight, a layer of heat insulating material and then another wall of steel plates.

The shale, after being discharged from the retorts, is cooled and taken to the by-product plant where it is treated to recover ammonia. The oil vapors pass into condensers from which the fixed gases are passed into washers for the double purpose of recovering the non-condensable gasoline and also any ammonia that may have been carried away. From here the gases pass to gas holders or gasometers from which it is withdrawn for the following two cycles: (1) gas holder to steam boiler to gas preheater to shale dryers to by-product recovery or air, (2) gas holder to gas preheater to retorts to condensers to exhausters and washers and back to gas holders.

The costs of retorting not including mining the shale, refining the oil or treating the by-products are given by Mr. Simpson as being 60¾ cents per ton. This figure includes taxes, depreciation, etc., and is figured on an average wage scale of $5.00 per day of eight hours.

The salient points to be noted in this process are: (1) heat for educing the oil gas from the shale is furnished on the interior of the retort by means of preheated gases, (2) no steam is used in the retort, (3) nothing but oil is recovered in the retort with the exception of slight amounts of ammonia evolved at the comparatively low temperatures used, (4) the bulk of the ammonia is recovered in the by-product plant after the oil has been removed from the shale in the retort, (5) very efficient heat conservation.

Mr. Simpson, who has examined the deposits of shale in Kentucky, states that he has not the least doubt but that using his process the retorting of Kentucky shales is commercially possible.

THE WORK OF MR. R. M. CATLIN.

Mr. R. M. Catlin has been experimenting for some years on a deposit of shale in Nevada and states, "My work has been entirely experimental and aimed entirely toward the economic treatment of our deposit, which is a paraffin shale containing no asphalt. In the course of years I have tried a great many methods and have no idea which of them may be of interest to your problem. In any case I am not prepared to publish my notes till I have completed my research."

THE WALLACE PROCESS.

This process, devised by Mr. G. W. Wallace of East St. Louis, Ill., is one that has attracted a good deal of favorable attention recently. Its classification places it under the head of vertical, intermittent retorts.

The retort proper consists of a vertical truncated pyramid with steeply sloping sides the large end being at the bottom and the dimensions being 7 feet long, 15 inches wide and 14 feet high with a thruput per oven of forty-eight tons per twenty-four hours. Around the outside of the retort enclosing walls are built and in the space between the retorts and these walls the heat for educing the oil gas from the shale is applied. The retort is, of course, tight closed at top and bottom. In the center of the retort is placed a metal duct which extends from the bottom to nearly the top and is of such a size that there is space of 3½ inches between it and the inner walls of the retort which space is kept filled with shale. This duct is covered at the top but is perforated with many holes around its perimeter and down its length through which the gases educed from the shale are withdrawn. The bottom of the perforated duct is connected to a suction pipe so that a slight vacuum may be maintained in the interior of the retort at all times and thus serve to withdraw the gases as soon as they may be formed.

The operation is as follows: The 3½-inch annular space between the walls of the retort and the interior duct is filled with shale crushed to a size of up to 2½ inches, suction is applied through the perforated duct and heat is given on the

outside of the retort the maximum heat, 1400 degrees F., being at the bottom. The heat attacks the shale nearest the outside of the retort first and evolves gases which are immediately drawn, by suction, through the cooler portions of the shale and into the perforated duct from where they go into condensers. The heat gradually works in toward the duct due both to the heat applied from the outside and that given off by the hot gasses as they pass through the cooler shale the evolved gases being continually withdrawn through the coolest portions of the retort, into the center duct and so passed out into the condenser system. In this way the gases are never subjected to a higher temperature than that at which they were formed and danger of cracking is eliminated. This action continues till all the gas has been evolved when the retort is shut down, the bottom removed and the spent shale discharged. At the same time the perforated center duct is removed and replaced by a fresh one thus enabling the used pipe to be thoroughly cleaned at leisure. The retort is then ready for a fresh charge and the operation is repeated.

The special points about this retort are: (1) the evolved oil gases are never subjected to a higher temperature than that at which they are formed thus eliminating the danger of cracking or breaking the oil gases up into non-condensable or fuel gas, (2) the heat is applied externally, (3) no steam is used in general though it may be used if desired, (4) the process is intermittent which latter point, in the opinion of the writer is apt to be a serious disadvantage.

As fare as costs and profits using this process are concerned I quote from an article by Floyd W. Parsons in the March 20, 1920, number of the Saturday Evening Post. "The other day, in an effort to get authentic operating figures, I sought Mr. Wallace and procured from him a comprehensive estimate of actual working costs based on preliminary but large scale practice. Reduced to the simplest form his figures indicate that at the present time (March, 1920) the cost of erecting a carbonizing plant to treat 90,000 tons of shale annually would be $220,000. The average cost per ton of shale carbonized would

be $1.37 divided as follows: fixed charges, including insurance, taxes, repairs and depreciation—32 cents; labor—50 cents; quarrying the shale—45 cents; extraction of ammonia—10 cents, making a total of $1.37. If the shale cannot be quarried and must be mined instead the cost would be $1.25 rather than 45 cents as stated above. According to Mr. Wallace the United States Bureau of Mines is authority for the statement that the oil can be topped for gasoline at a cost of 10 cents a barrel. He believes this figure is correct. The total cost of mining, carbonizing (retorting) and refining each ton of shale would be $2.47 divided as follows: overhead and transportation—50 cents; carbonizing—$1.37; cost of refining—60 cents; making a total of $2.47.

"As to the revenue to be derived from each ton the figures produce the following: Gasoline, 8.9 gallons @ 20 cents per gallon, $1.78; paraffin, 23 pounds @ 6 cents per pound, $1.38; ammonium sulphate, 17.2 pounds @ 5 cents per pound, 86 cents; lubricating oils, 17.65 gallons @ 20 cents per gallon, $3.53; total, $7.55.

"Deducting all the costs from the above revenue we have a net profit in the operation of $5.08 per ton. Mr. Wallace bases his figures on a yield of 42 gallons of oil per ton. * * * He says that it is not unusual to expect that the oil will refine out from $7.00 to $8.00 per barrel."

Mr. Wallace has very kindly supplied the writer with the following data concerning a plant that he has erected for the D'Arcy Exploration Co., near Moncton, N. B. The plant, which is in daily operation, consists of one oven of 15 cubic feet capacity. It is eleven feet high, has an average cross section of 14 inches by 30 inches and holds a charge of from 800 to 1,000 pounds of shale. The plant is complete with condensers, scrubbers and all auxiliary equipment.

The average results obtained in the above plant after an operation of one month and with approximately 100 tons retorted, is as follows: (1) Average time of retorting shale, 2.13 hours; (2) pounds of shale retorted per square foot of retort per hour, 5.01; (3) yield oil per ton, 28.21 imperial gal-

lons (35.85 U. S. gallons); (4) laboratory yield of a check sample by Scotch testing method, 28.27 imperial gallons; (5) specific gravity of crude oil, .898; initial boiling point, 187 degrees F.; end point, 702 degrees F.; (6) crude naphtha, 22.95%; green oil, 71.80%, distillation loss, volume, 5.25%; coke from oil, per cent by weight, 3.55%; unsaturated hydrocarbons, crude naphtha, 7.16% and green oil, 27.60%.

It is not known that any Kentucky oil shale has been tested in a Wallace retort. There is no reason why it should not work as well, or give as good results, however, as shale from any other locality.

THE GALLOUPE PROCESS.

This oil shale retorting process developed by Mr. J. H. Galloupe of Denver, Colorado, has a vertical retort and is of the modified Scotch type. It consists, essentially, of two cylinders one placed concentrically within the other leaving an annular space of 4 inches between the two in which space the shale is placed. The inner cylinder is 16 inches in diameter and the outer one 24 inches the height varying from 18 feet to 21 feet according to distillation requirements. Both the outer and inner cylinders are equipped with ledges or vanes placed spirally and so designed that as the inner cylinder slowly revolves there will be a constant agitation which not only prevents clogging but also moves the shale slowly from the top to the bottom of the retort.

The heat is applied to these cylinders externally, that is on the interior of the inner cylinder and on the exterior of the outer one, and in both cases from the bottom upward so that the lower portion of the retort is subjected to the greatest temperature, the temperature range being from 1100 to 1340 degrees F. at the bottom to 212 degrees F. at the top. The oil gas is withdrawn as formed and it is claimed that partial fractionation takes place in the operation of retorting, that is, that by withdrawing the gases from different points and then condensing these gases separately, different grades of oil are obtained without further refining. In the opinion of the writer it is an extremely difficult if not impossible thing

to get a satisfactory product in this way and it would be preferable to condense all the oil gas together and then refine the crude as is done in ordinary practice with natural petroleum.

The retort is so constructed that the lower portions which are subjected to the greatest heat and wear are easily removed and replaced without causing any long shutdown. The materials used in the retort are wholly cast iron and the thruput per 24 hours is given as eight tons with high grade and twelve tons with low grade shale.

The salient points of this retort are, (1) continuous movement and agitation of shale through a vertical annular space the movement being due to slow rotation of the inner cylinder, (2) application of external heat to two sides of the shale at the same time, (3) no steam used. So far as is known, no Kentucky oil shale has been treated in a Galloupe retort.

THE DAY PROCESS.

This process developed by Dr. David T. Day of Washington, D. C., is of the horizontal type of retort. The retort proper is made of steel and the shale is advanced through its length by means of a screw conveyor. The shale is crushed to egg size, fed into the retort and passed through at the rate of 20 tons in 34 hours. The heat is applied externally and is furnished by the waste gas, the temperature required being 700 degrees F. The gases and vapors are withdrawn as in an oil still. It is understood that this process has been tried out in California and Texas shales, but so far as is known no experimental work has been done on the oil shales of Kentucky by this process.

THE JENSON STAGE EDUCTION PROCESS.

This system of retorting, invented by Mr. J. B. Jenson of Salt Lake City, Utah, was designed specially for use on the fluxing shales of the West and the retorts are of the horizontal type. A commercial retorting unit, it consists of nine, horizontal, cast iron cylinders, eighteen feet long, placed at three-foot centers one above the other, the whole being enclosed in brick work, and the shale being moved through each cylinder

by means of screw conveyors. The fuel used is gas formed in the process and it is applied under the lower chamber, the temperature required being 250 degrees F. for the first or top cylinder and graduating to from 900 to 1200 degrees F. for the last or bottom cylinder, this latter temperature varying with the structure of the shale. As stated above the heat is applied under the lowest cylinder and the hot gases are then led progressively upward and around each of the cylinders above being finally discharged at the top and thus giving the graduated heat mentioned. The thruput is given as 50 tons per 24 hours and the gas and oil vapors evolved during the process are withdrawn from the retorts by an exhauster through four pipes spaced at about equal intervals up and down the height of the nine cylinders. By using this means of collecting the vapors and by then condensing the vapors from each pipe separately a partial fractionation of oils in the retorting process itself is claimed.

The shale, grading in size from a half an inch down to fines, is introduced into one end of the top retort through a hopper, which hopper is kept full thus forming an air and gas tight seal. The screw conveyor then carries it through this upper cylinder where it is subjected to a temperature of about 250 degrees F. as a consequence of which the water is driven off and the shale warmed. After passing through this upper cylinder the shale drops down into the one next below where it is picked up by a screw conveyor and passed through this second cylinder the direction of travel being opposite to that taken in the first case. Here it is subjected to a slightly increased heat and the vapors that will come off at this temperature are educed.

After passing through the second cylinder the shale drops down to the third one and passes through it in a direction opposite to that taken in the second one and here it is again subjected to a slightly higher temperature where the gases evolved at the temperature used are educed. This procedure continues, as outlined, till the shale has passed through the entire nine cylinders, at which time all the oil and gas will

have been driven off, when it is discharged by screw conveyor into water this water affording a seal against any leakage of air into the retort or of gas from it. Treating the shale in stages in this way is claimed to prevent any breaking up of the oil gases formed and to also overcome the fluxing tendency of high grade shales. Steam may be used when water is available, otherwise not. When used it is introduced into the lowest, which is also the hottest, cylinder.

The outstanding points about this system are (1) stage eduction, that is, practically a separate treatment of shale in each of nine cylinders, (2) shale conveyed through each cylinder by screw conveyor, (3) heat applied externally, (4) vapors withdrawn at four separate and distinct points and condensed separately.

As before mentioned this system was designed primarily for treating the fluxing shales of the Western part of the United States and, this being the case, it is necessarily overcomplicated for the non-fluxing shales of Kentucky. However, Mr. Jenson has recently "perfected two additional retorts one of which was specially designed for the low grade non-fluxing shales in which the ammonia product is of special interest. This retort has large capacity, operates cheaply and is not expensive either to construct or to keep in repair. "This retort is known as the Devonian Type." He continues, "Our high pressure retort should also be applicable to your Kentucky shales although it was designed originally to treat the metal bearing shales of Colorado and Utah. It is a high pressure retort and almost invariably gives an increased yield of oil over other types of retorts and was not designed for the recovery of ammonia."

The two retorts mentioned and designed by Mr. Jenson are not yet at the point in their development where detailed information can be given, due to the fact that foreign patents have not yet been allowed. Mr. Jenson, himself, realizes that stage eduction is not the real solution of the problem for Kentucky shales, and already has several improvements which he hopes will perfect his process for use here.

THE SCOTT PROCESS.

This system of oil shale retorting, owned by the General Eduction Co. of Colorado Springs, Col., is one that has been mentioned rather frequently in connection with Kentucky shales. In fact, the Devon Oil Shale Products Co. of Cincinnati is reported at the present time to be making an installation of an eight retort plant at its property near Clay City.

The retort is of the vertical type and is made in sizes to have a capacity of twenty, thirty or forty tons per 24 hours, the dimensions with the latter capacity being 12x22x50 feet high. The materials of construction are steel, silica, carborundum brick and concrete. The retort proper consists of an upper and a lower portion connected by an expansion joint so designed that the connection between the two portions may be closed when desired. The vapors educed from the shale in the lower portion of the retort may either be withdrawn through an outlet pipe at the top of this portion, that is, at about half way of the total height of the retort, or else may be passed around the expansion joint and be brought into contact with the shale in the upper portion of the retort, thus preheating it. There is also a valve in the by pass pipe so that the vapors may be prevented from entering the upper portion of the retort if desired.

In this upper part there is a feeding arrangement and an outlet pipe to remove the oil gases, while the bottom of the lower portion is closed, the shale being removed by means of a screw conveyor, everything being kept gas and air tight.

A brick enclosing wall is built around the retort proper in such a way as to leave an annular ring, and it is here that the gas is burnt to supply the heat for educing the oil from the shale, the hot waste gases of combustion being led off through a stack. The draft is regulated by dampers placed in the pipe leading from the annular ring into the stack. Steam, superheated to 900 degrees F. at atmospheric pressure or about 687 degrees of superheat, is introduced into the bottom of the lower portion of the retort and, the temperature being sufficiently high, is broken up so that it reacts with both the

nitrogen and fixed carbon of the shale to form ammonia and water gas respectively as well as acting beneficially on the oil vapors formed.

For purposes of illustration suppose the retort to be running. The upper portion is filled with shale crushed to from 1 inch to 1.5 inches and gases, formed in the lower portion are passing through it, the shale itself being stationary. This results in this shale being preheated to a certain extent thus driving off the moisture. At the same time a temperature of from 900 to 1800 degrees F. is being applied to the lower portion of the retort with the result that the oil vapors are being driven off and, as the discharge is continuous, this lower portion is being gradually emptied. At the end of three hours the gate between the two portions is opened and the preheated charge from the upper part is allowed to drop into the lower part, the gates are closed, the upper part refilled and the operation is repeated. The spent shale after being discharged is lifted by a bucket chain, sprayed with hot water to remove the potash and then goes to the dump. The educed vapors and gases are condensed and scrubbed as in any process.

The salient points of this process are, (1) the shale is preheated, (2) intermittent feed and continuous discharge, (3) the heat is applied externally the fuel used being the non-condensable gases made in the process, (4) superheated steam is used.

The claim is made that this retort works satisfactorily on both Western and Kentucky shales and the writer sees no reason why it should not do so, in his opinion, the difficulties to be encountered in continuous commercial operation being more apt to be mechanical rather than chemical.

THE STALMAN PROCESS.

This process, developed by Mr. Otto Stalman of Salt Lake City, Utah, embodies a retort of the vertical type. Mr. Stalman for a number of years was connected with the oil shale industry of Scotland and, since interesting himself in the shales of this country, has made extensive tests on those coming from the western states as well as a few tests on Kentucky

shales. According to Mr. Stalman it has been his object to construct a retort which will be easily adapted, by simple modifications, to the successful and profitable treatment of all the western shales and the results obtained, he says, have fully justified expectations.

The retort used is cast of a particular mixture of iron which has been found to resist changing temperatures in the retort oven and which also insures as nearly sound a casting as possible. It has the shape of the frustrum of a cone being 1 foot 6 inches inside measurement at the top or charging end, 2 feet 3 inches at the bottom or discharge end and 18 feet high, the casting being 1.5 inches thick. A tuyere box is placed around the lower portion of the retort so as to allow for the admission of superheated steam to the charge. The top of the retort connects to the charging hopper where the charge is stored and, at the same time, preheated. At the bottom of the retort is an automatic discharging device consisting essentially of a revolving disk. This arrangement not only furnishes an easily regulated and even discharge but, by means of a device connected to it, provides a means whereby the charge may be loosened should it clinker and whereby it may be continuously agitated, if necessary. This precaution insures an even descent of the shale through the retort. In any event the discharge mechanism is so adjusted that the level of the top of the charge is always maintained at the same place and at the same distance below the gas outlet pipe near the top of the retort and this is done in order to avoid carrying off any more dust with the gas and steam into the condensing system than is absolutely necessary.

Charging hopper, retort and automatic discharge are so connected that they are hermetically sealed and air tight gates are provided so that charging and discharging may take place without any interruption of the operation and without the possibility of air entering the retort or gas and steam escaping from it except through the discharge pipe provided for the purpose which pipe is situated near the top of the retort and from whence the gas and steam are led to the condenser.

Four retorts are placed in an oven and as many ovens as necessary to satisfy the capacity desired are built into a bench. The number of retorts required for a given capacity depends entirely on the time necessary for complete distillation of the particular shale being treated and this time will vary, as shown by Mr. Stalman's experiments from four to eight hours. The retort described, then, has a twenty-four hour thruput of nine tons based on a distillation time of four hours. A plant of four ovens or sixteen retorts would, therefore, treat about 150 tons per day but for practical purposes Mr. Stalman says that this size plant should be figured to give 100 tons per 24 hours.

The retorts are charged by a conveyor which carries the shale from the storage bins to the charging hopper, it having been broken, previous to reaching the storage bins, to a maximum size of six inches by a set of spike rolls. It is advised to remove the fine material made in mining and crushing, 1/4 inch size and less, before treating and to treat these two classes of material separately. The spent shale drops from the automatic discharge into a storage bin situated beneath the retort and is thence carried by conveyors to the waste dump.

The steam, which enters the retort through the tuyeres previously mentioned, near the bottom of the retort, is taken from the boilers at a pressure of 1.5 lbs. per sq. in. and is superheated during its passage through a series of coiled pipes built in the interior of each oven, before entering the retorts at a temperature of from 600 to 850 degrees F., the most suitable temperature depending on the character of the shale being treated. Suitable baffles, built in the interior of the oven, cause the products of combustion to pass gradually from the bottom of the retort to the top of the oven where they are led off through a chimney.

The products of the retort are hydrocarbon gases, steam with ammonia, and spent shale. The latter is free from oil producing matter and goes to the dump as outlined above. The former products leave the retort together by a branch pipe near the top through which they enter the main gas conduit

common to all the retorts of the unit and are led to the condenser.

This condenser, in this system, is a special, patented device and the products are, as they are with any condenser used for this purpose, gas, crude oil and ammonia water. However, in this system, partial fractionation takes place in the condenser and six classes of oil of different boiling points and specific gravities are made. Each of these six classes of oil together with its ammonia water is then led by short pipe lines to special, individual separators where the ammonia water is separated from the crude oil. From the separators the oil is led through a pipe line to its individual storage tank and from there to the refinery while the ammonia water goes to the ammonia water storage tank for subsequent treatment in the ammonium sulphate plant.

The fixed or fuel gas is withdrawn from the condenser by an exhaust fan which, being in the closed circuit of condenser and retort, aids the passage of the gases through the main gas conduit to the condensers, and then forces them through a scrubber where any ammonia still retained in the gas is extracted by water scrubbing. From the ammonia scrubber the gas, now ammonia free, passes into the gasoline absorption tower where the gasoline, from two to four gallons per thousand cubic feet of gas, contained in it is removed by being absorbed in an oil specifically heavier than gasoline. This oil is then subsequently treated to remove the gasoline. The final permanent gas then goes to a gasometer from which it is withdrawn, as necessary, for fuel purposes.

The ammonia water from both the separators and the ammonia scrubbers is conducted to the ammonium sulphate plant where the ammonia is volatilized and the ammonia gas then led through sulphuric acid the action of the two forming ammonium sulphate which is precipitated out, freed from water, dried and is then ready for the market.

The economic products of the distillation plant are, the crude oil, the gas, the gasoline from the absorption plant and the ammonium sulphate. The latter two are ready for the

market, the gas is used in the plant as a fuel while the crude oil is stored for treatment in the refinery.

According to Mr. Stalman the cost of a plant as outlined above is from $65,000 to $100,000 depending on local conditions and the cost of a 300 ton daily plant for distillation and a Wells System refinery for 400 barrels of crude oil is from $450,000 to $500,000.

The outstanding points about this system are, (1) vertical, continuous retort, (2) heat applied externally, (3) shale not finely crushed, (4) steam used, (5) fractional condensation in a special condenser, (6) maximum production of ammonium sulphate not accomplished.

Mr. Stalman has kindly furnished for the purposes of this paper the following results of tests on both Western and Kentucky shales though it may be said that he has done but little work on the latter.

An average of several lots of Western shale producing about 50 gallons of crude oil per ton with from 15 to 20 lbs. of ammonium sulphate and about 3000 cubic feet of fuel gas, furnished, on refining, the following products ready for the market; gasoline —9%, 460 degrees F. end point; gas oil—29%, 37.7 Be.; motor oil 36%, flash point 375, fire 445, viscosity 106 @ 70 degrees; wax—6%, 130.5 melting point; pitch—10%; loss—10%.

Two charges of 450 lbs. each of Kentucky shale gave, after a four hour treatment at an average temperature of charge of 847 degrees F. at the bottom of the retort and 504 degrees at the top, a yield of 114.5 pounds of oil of a specific gravity at 60 degrees F. of .979 or 13 Be. which figures to 31.2 gallons per ton, the gas obtained amounting to 3,333 cu. ft. per ton and the ammonium sulphate to 4 lbs. per ton. An analysis of the spent shale showed the oil entirely removed.

A test of 460 pounds of a different Kentucky shale gave, after a four-hour treatment at an average temperature of charge of 851 degrees F. at the bottom of the retort and 509 degrees at the top, a yield of 43 lbs. of oil of a specific gravity of .943 or 18 Be., which figures to 23.75 gallons per ton, the

gas obtained amounting to 1,820 cubic feet per ton and the ammonium sulphate to 6.75 pounds per ton.

It is worthy of note that the ammonium sulphate obtained is small and only a small part of that which may be recovered from the average Kentucky shale as, as a rule, these shales run rather high in nitrogen. The explanation of this fact is, undoubtedly, that the maximum temperature used in distillation, less than 900 degrees F., is entirely too low to get an appreciable recovery of ammonia. Therefore, as far as Kentucky shales, at least, are concerned, the Stalman retort should be considered as a producer of oil and not of both oil and ammonium sulphate and if, as, in the writer's opinion, will be the case with Kentucky shales because of their high nitrogen content, a maximum recovery of ammonia is desirable, a subsequent treatment had better be given the spent shale for this purpose.

In the foregoing discussion no attempt has been made to cover all the different processes for recovering oil from shale, but merely to select types to illustrate the different angles at which the problem is being attacked. All of the systems described, with the exception of the one developed by Mr. E. E. Hedges and the writer at the University of Kentucky, have been designed primarily for use with Western shales. The inference is not, however, that those processes and plants developed for Western shales will not work on Kentucky shales, but merely that, in most cases, their applicability to Kentucky shales has yet to be proven.

The value of the unmined crude oil and associated by-products locked within the oil shales of this State is very great. Thinking men are aware that the dawn of the day of shale development is at hand. That American ingenuity will fashion, if it has not already fashioned, the key which will unlock the treasury of oil close held within the Knobs of Kentucky, there can be no doubt. Less spectacular than crude oil from flowing wells, but more so than coal dug from mines, the com-

ing oil shale industry of Kentucky will call into play alertness, aggressiveness and trained intelligence. It offers as rewards great wealth and satisfaction in the ultimate solution of a difficult new industrial problem.